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# REDESIGN OF FLIGHT SPACE SHUTTLE MAIN ENGINE NOZZLE G-15 SEAL AREA BASED ON THE THERMAL ANALYSIS AND FLOW MODELS


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## INTRODUCTION

In the Space Shuttle Main Engine (SSME), the main combustion chamber (MCC) and nozzle are combustion devices used for transporting the supersonic turbulent combustion gases from the injector plate to the exit nozzle plane where the thrust is produced to help propel the shuttle orbiter. The liquid hydrogen fuel and liquid oxygen oxidizer are pumped by low and high pressure turbopumps to the injectors. Then, the fuel mixture is ignited through the converging-diverging MCC to an expansion ratio of 5:1 to the MCC exit plane from the MCC throat. The nozzle which is mated to the MCC using a circumferential ring of bolts further expands the supersonic combustion gas to an area ratio of 77.5:1 to the nozzle exit plane from the MCC throat to produce the required thrust. At the interface between the MCC and nozzle, there exists a G-15 seal area to prevent hot gases from escaping the MCC/nozzle into the aft end of the shuttle orbiter. A problem has evolved with the INCO-718 metal bellows seal in the G-15 seal area. After post-engine and post-flight inspections, a discoloration or bluing of the bellows seal and in one case, a stress rupture crack in the bellows seal has occurred.

In this study, the main objective is to understand the present sealing area response to environmental conditions of the supersonic turbulent combustion gases which has led to both stress rupture cracks and hot gas leakage. A review of the existing thermal analysis and flow modelling has been performed of the present design and seal alternatives have been suggested to possibly reduce or eliminate the hot gas flow recirculation problem and the associated seal cracking.

## THERMAL ANALYSIS and FLOW MODELLING

Several thermal analysis and flow modelling studies have been performed to identify the causes of the G-15 bellows seal discoloration and stress rupture problem. McConnaughey [1] and others performed a computational fluid mechanics study motivated by SSME post-flight and post-test inspections identifying the G-15 seal problem. The flow field in the G-15 region was created by a protrusion of the nozzle coolant tubes brazed on the interior of the nozzle shell. Too much protrusion of the coolant tubes created a forward face step preceeded by a narrow G-15 cavity existing between the mating MCC/nozzle interface. The forward step caused a supersonic shock to form at the leading edge of the MCC lip while another shock formed when the main flow stream reattached with the nozzle tubes downstream of the G-15 cavity. This protrusion and gap distance have been identified as the prime causes for hot gas ingestion in the G-15 cavity, thus, causing an extreme temperature increase of the bellows seal. The reason for coolant tube protrusion is due to an inherent out-of-roundness of the nozzle when mating with the MCC. So, areas of maximum coolant nozzle protrusion into the hot gas free stream is strongly correlated to bellows seal discoloration. However, it should be noted that some cases exist of no protrusion of the coolant tubes into the nozzle free stream did cause some bellow seal damage, but, was minor when compared to the protrusion and gap cases.

A study by Sharma, Dang, and Kassner [2] used the Korst theory to model a forward facing protrusion. Based on the interaction between dissipative shear flow and the adjacent free stream along with the conservation of mass in the wake, there were four flow components analyzed. These components were flow approaching trailing edge of the MCC, expansion around the trailing edge, mixing with the free-jet boundary over the cavity and recompression at the end of the wake at the protruding nozzle coolant tubes. This approach allowed for a unique stable solution for base pressures used to calculate cavity pressure, injection flow rate in the cavity, and gas temperature of the injected flow. This method agreed with the CFD approach concerning the creation of hot gas recirculation within the cavity causing high bellows seal temperatures.

A study by Roman [3] created a thermal-flow model using the SINDA computer program to predict cavity and seal temperatures. This approach also included the FRI (Flow Recirculation Inhibitor) which was a material inserted into the G-15 seal cavity to reduce or prevent hot gas recirculation creating the high seal temperatures. The FRI is made of Nextel material sewed around the nozzle tubes before the tubes enter the outlet coolant manifold. Also, the FRI is glued with uralite to the nozzle lip. The FRI has experienced some burning in testing due to the protrusion and gap dimensions being too large allowing for more hot gas ingestion.

## SEALING ALTERNATIVES

Based on the thermal and flow models, a review of the literature on sealing was performed to identify possible replacements of the bellows seal. Seals are classified into two basic categories which are static and dynamic. Static seals are used when the sealing surfaces experience no relative motion between the parts except due to load and thermal expansions. Dynamic seals are used to seal a stationary surface with a rotating or reciprocating surface. After reviewing various seal texts [4] & [5], some recommended changes are shown in Figures 1 through 4. These recommended seals are static-type. In all of these figures, a recommendation of the MCC lip extension and possible nozzle lip extension were made to help diminish the protrusion and gap effect. It should be noted that the current INCO 718 bellows seal is a load assisted seal with Teflon covered ends loaded in compression due to the bolts and engine thrust. In Figure 1, the usage of a metallic U,C,K,E,V, or X seal can be used to replace the bellows seal in a shortened cavity next to the bolt circle. It is recommended that a secondary seal be used like a metallic gasket around the bolt circle. In Figures 2 & 3, a piston ring and labyrinth seal were used as a primary seal whereas a shortened bellows seal would be a secondary seal. In Figure 4, a recommendation was made to not change the type of seal, but, to tap into an adjacent MCC coolant passage to lower the bellows seal temperature since stress rupture cracks occur due to the loss of ductility of the Inconel 718 material at excessive high temperatures.

## RECOMMENDATIONS

Several recommendations were made based on this study.

1. Use a different type of metal seal in the G-15 seal area and use a type of secondary seal in the bolt circle area.

2. Evaluate other high temperature materials for possible replacement of INCO 718. (other metals or bimetallic composite combinations)

3. Investigate the feasibility of reconstructing the MCC lip to block the cavity and possible redesign of the nozzle lip to avoid usage of the FRI.

4. Establish criteria for the improvement of stack and brazing nozzle tubes to avoid a protrusion circumferentially at the MCC/nozzle interface.

5. Investigate the possibility of tapping into the MCC coolant passage adjacent to the bellows seal to keep the temperature from reaching the stress rupture temperature for Inconel 718.

## REFERENCES

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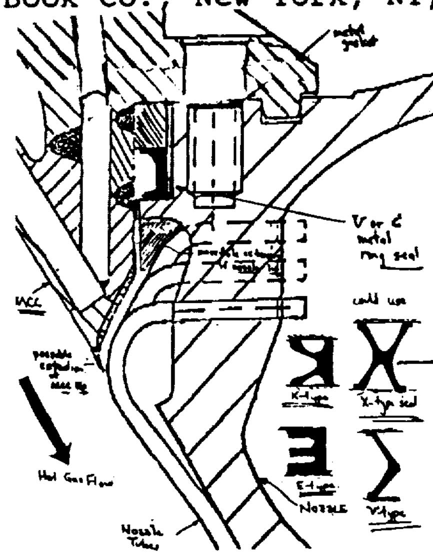


Figure 1: U,C,K,V,E,& X Seals

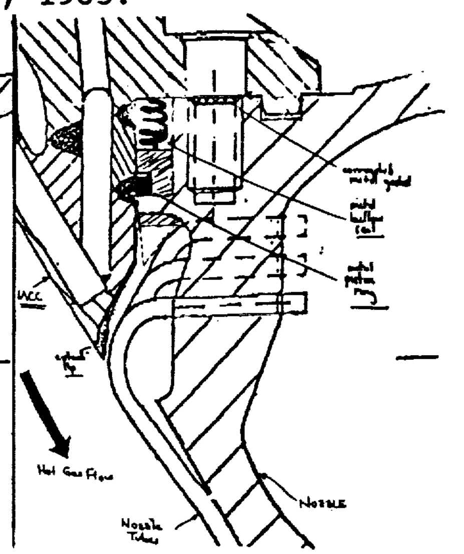


Figure 2: Piston Ring - Bellows Seal

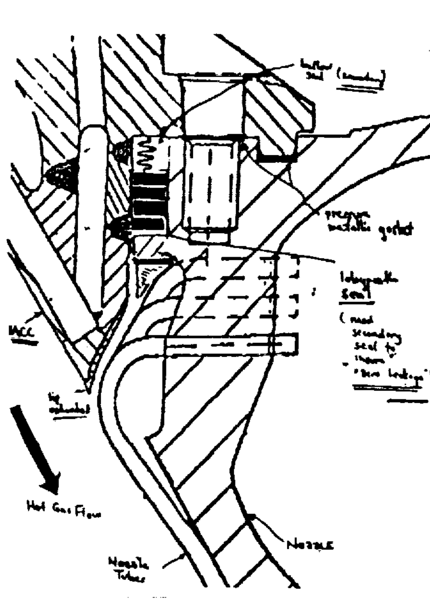


Figure 3: Labyrinth Seal - Bellow Seal

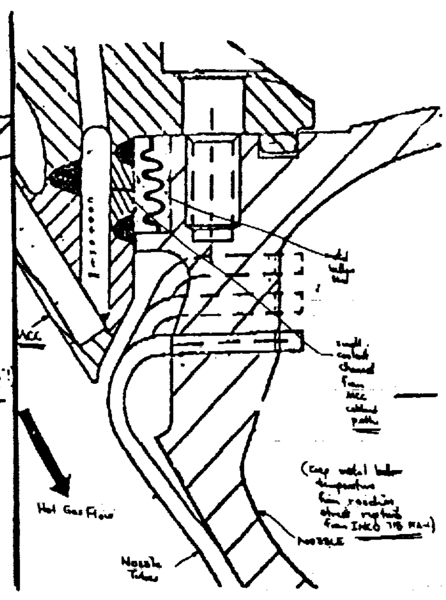


Figure 4: Coolant Passage to Bellows Seal